ON THE PROPERTIES OF THE FIELD SURROUNDING A CROOKES TUBE.

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(Plates II and III.)

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The investigation of the subject implied by the title of this article was suggested by the unexpected presence on some radiographic records of peculiar markings outlining certain bodies *below* the plate, in addition to the expected shadows of the objects above the plate—*i.e.*, between the sensitive film and the vacuum tube.

While using an iron tripod stand with a ring-shaped top as a support for a radiographic plate, it was noticed that the plate when exposed to X-rays seemed to be influenced locally by the presence of the iron ring below. For after exposing a circular piece of bronze placed on the upper side of the plate which had rested on the stand during exposure, the development showed that just above the metal of the stand the plate was appreciably less affected through the bronze than under that portion of the latter which had not been over the metal support. This startling observation suggested at once more careful investigation, especially since on first thought it would seem that if the metal below the plate could have any effect, the result should be quite the contrary to what was observed—*i.e.*, if the metal below sends off "emanations" of some sort which might produce an effect on the sensitive film, the latter would be expected to show an increased density where influenced both by the rays from above and by the emanations from beneath.

Apparent anomalies have on several occasions been noticed on radiographic plates, some similar to that just mentioned, but these have never been definite enough to invite special investigation.

A large number of experiments were made at once in rapid succession with strips and plates of various substances both below and above the sensitive film, with results always the same in character though differing in intensity of effect in different experiments and with different materials. As examples of the character of some of the tests, sheets of paraffin, mica, and of aluminum were successively placed between the under metals and the film, with the result that the effect in every case was similar, only a little less intense

than when no screen was interposed. The original records of all these experiments and the particular conditions in each case have been carefully preserved. A single figure will be enough to illustrate this effect.

Fig. 1 shows the result when two zinc blocks, one of them polished, were placed below the photographic plate upon which the latter rested. On this were a strip of copper, one of lead, a triangular and thicker piece of uranium, and a piece of metallic indium about one millimetre thick and three centimetres square. Fifteen centimetres above this combination the discharge tube was operated for twenty-five minutes, the rays being directed downward. The zinc blocks were below the lateral edges of the plate and covered each about a third of its area. There certainly is nothing ambiguous about the result, and the degree of polish seems to have nothing to do with the effect. The middle third is distinctly darker than the rest in those parts just under the metal pieces.

The transverse strip in the middle was lead and is distinctly less pervious than the copper on the left.

In looking up some of the early work of Roentgen, I found that one of his experiments was almost identical in character with those just described, but less strenuous and designed for quite a different purpose.[1] He arranged star-shaped pieces of four metals, platinum, lead, zinc and aluminum, covered by a light-protected photographic plate, film towards the stars and glass towards the tube. On development after exposure to the rays from a focus tube identical in principle with that universally used at present, the metal stars showed darker than the rest of the ground. The purpose of his experiment was to demonstrate a possible reflection from the metal stars, and the result obtained was interpreted as conclusive evidence at the time that such was the case.

For obvious reasons it seemed desirable to repeat Roentgen's experiment as nearly as possible as he made it. This was done with some difficulty, on account of the fact that the apparatus in use developed rays of such penetrating power that the glass backing of the sensitive film offered little obstruction, and even with a very short exposure the whole film was so dense as to show nothing of the metal pieces.

Increasing the thickness of the glass made it possible, after several trials and by using a contrast-developer especially prepared for

over-exposures, to produce a fairly definite result, as shown in Fig. 2. It is to be noted, however, that the parts of the film just next the pieces are *less* dense than the rest—*i.e.*, the shadows are light on a darker ground.

Fig. 3 shows the result when to the glass of ordinary thickness was added thick blocks of zinc. The characteristics of these two plates are identical, except that the latter is more dense and shows greater contrast.

In Fig 4 we have reproduced a plate made just as was that of Fig. 3, except that the exposure was thirty minutes instead of fifteen. The appearance is certainly remarkable, for though the direct X-rays had been entirely cut off by the zinc blocks the shadows are exactly as would have been produced by reversing the process and exposing directly to the Roentgen rays, though for a much briefer time.

The influence on the side of the plate remote from the tube seems to have more than neutralized the Roentgen reflection effect, and the more so the greater the exposure.

From these three experiments it seems probable that with a much less powerful X-ray generator, a suitable exposure would show the result noted by Roentgen. As is seen below, this was probably not due to reflection.

The next plate (Fig. 5) shows the impression of the ring stand, above spoken of, when the former was covered with a sheet of copper about a millimetre thick and exposed twenty-four minutes. In Fig. 6 the stand is replaced by a brass ring supported by a block of wood. The penumbral effect around the inside edge is to be noted.

As an interesting modification of this experiment I asked one of my associates, Dr. Richards, to hold his hand beneath the plate, protected above with thick metal blocks, and exposed the combination five minutes. The result (see Fig. 7), though lacking in definition, is quite like the first radiographs made without a focus tube.

We seem now to be led up to a satisfactory explanation of what we have observed so far—*i.e.*, of this apparent "nether effect" reaching completely around into the shadow of an obstruction totally impervious to X-rays proper, and acting in a direction just opposite to that of the rays from the tube.

It must be noted here that so-called "X-ray diffusion" has long been recognized, and an early experiment[2] with a fluoroscope

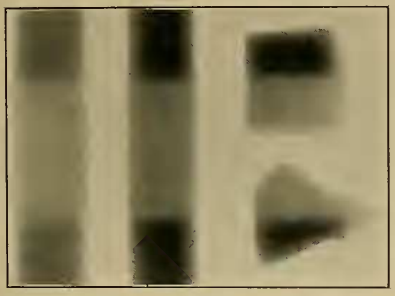

FIG. 1.

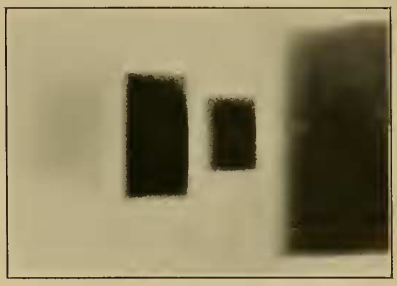

FIG. 4.

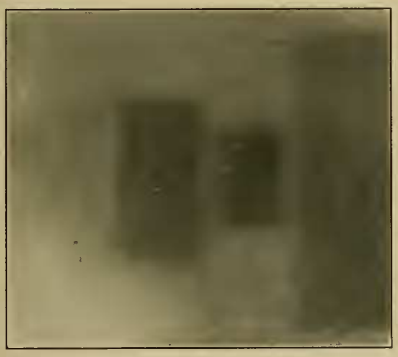

FIG. 2.

FIG. 5.

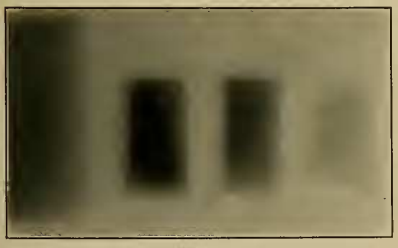

FIG. 3.

FIG. 6.

behind a thick steel plate was explained variously, the most thoughtful suggestion perhaps being by Prof. Elihu Thomson, who proposed that the screen was rendered luminous by the action of X-rays reflected from various objects in the room.

From all the experiments yet made in the effort to account for what at first seemed to be, to say the least, a paradox of science, it looks as if the whole space field in the neighborhood of a focus Crookes tube in operation is full of some sort of subtle energy, radiant possibly, but incapable of affecting the human eye, though leaving its mark on a photographic plate.

It was found by Sagnac[3] that many bodies in the path of X-rays acquire the property of emitting emanations of some sort capable of causing fluorescence and photographic action.

Undoubtedly then the effects above described are due to the secondary radio-activity of the air, the table and other bodies favorably located to be impinged by the X-rays directly.

In order to gain more knowledge of the possible limitations of this "radious" field, metal tubes of various sizes and lengths were placed on the plate, and now for convenience the entire local order of the articles used was completely reversed. Furthermore, the Crookes tube *was enclosed in a black wooden light-tight box, and all experiments were made in the night, so that every trace of optical light might be more easily excluded.* We have now the tube in its box, so placed that the axis of the ray-cone is directed vertically upwards. On the upper surface of the box and over the focus of the tube is a bundle of lead plates about one centimetre thick. On this, film upward, is the photographic plate.

This arrangement differs from that of Sagnac in that the *fluorescent light* from his tube was not filtered out, as it is here, by the box enclosing the X-ray bulb.

In Fig. 8 we have the result of a twenty-three minute exposure, when a brass tube five centimetres high, eight centimetres in diameter and three millimetres thick is placed on the plate, the tube being open at the top. This experiment was repeated with a thick block of pine wood, placed on top of the brass tube, with no change in result. The condition of the enclosed space is independent of the presence of the wood, and the enclosed area of the film is much affected.

When however the tube is covered with a thick block of zinc, this seems to protect the sensitive film completely from outside

influence, for the density of the exposure was found to be the same over the area within as under the edge of the tube, *i.e.*, nearly zero.

It does not seem possible that this effect could result entirely from the action of the Sagnac rays, since little if any of the area at the base of the brass cylinders can be reached by a straight line from any particle of matter traversed by the direct X-rays. It can be explained as a tertiary effect, produced by the air or wood just over the top, which had received its energy from the secondary emanations of other bodies in the direct path of the X-rays, or possibly the secondary or Sagnac rays may be of the nature of dark phosphorescence, *i.e.*, lasting for a time after the cause has ceased. Reasons for favoring the latter view appear as a conclusion to this paper. In this case the diffusion of the air in the room would cause the whole space to be uniformly active.

The arrangement just described suggested some easy tests on reflecting or diffusing power of different surfaces, as Sagnac had made in a different way in his investigations. In a brass tube similar to the one used above, at two points 90° apart, windows were cut 1 centimetre wide and 4.5 centimetres high. This tube was capped with zinc or lead, so that nothing could enter except through the windows. It was placed on the plate and a polished zinc block arranged opposite one window. Fig. 9 shows the result, all other conditions being as before. The exposure was twenty minutes. The streak entering the window opposite the zinc is unmistakable, and the diffused "radious" state of the whole enclosed space is demonstrated by noting the line of contact of the tube. A little brush in at the other window, too, is clearly distinguishable though faint. It seemed most desirable now, if possible, to make this phenomenon optically visible, and with this in view the following arrangement was set up:

Instead of the smaller lead block used with the radiographic plates, sheets aggregating one centimetre in thickness and a little larger than a 7x9 screen were placed on the box. On this a barium platinum cyanide screen was placed, face up, but covered with a piece of pasteboard. In this cover a circular hole was cut just the outside diameter of the window tube described above, through which the latter was placed, resting on the fluorescent screen. Its length was doubled by placing an extension on top. This was found by experiment effectually to exclude all noticeable influence except that through the windows.

FIG. 7.

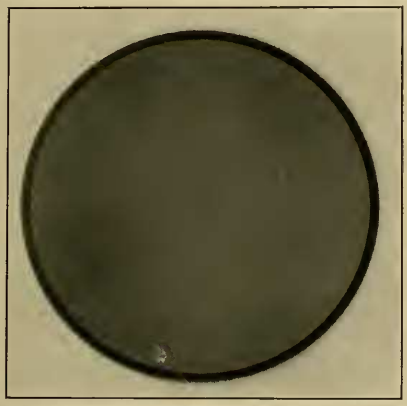

FIG. 8.

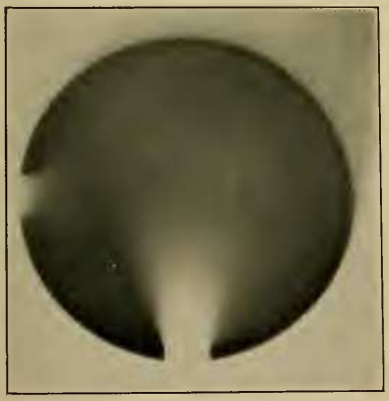

FIG. 9.

FIG. 10.

FIG. 11.

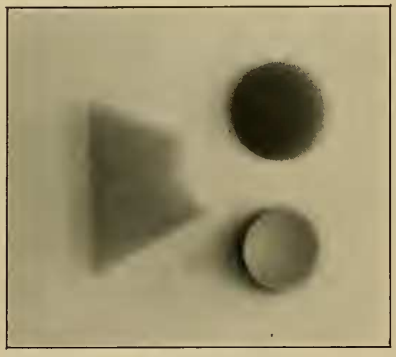

FIG. 12.